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FPDL

ANALYSIS OF AN AIRCRAFT TIRE

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AEROSPACE STRUCTURES
INFORMATION AND ANALYSIS CENTER

OPERATED FOR THE AIRFORCE FLIGHT DYNAMICS LABORATORY
BY ANAMET LABORATORIES, INC.

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This report summarizes the analysis conducted to determine the stresses in an isotropic cast carcass tire and in a bias-ply tire using the MARC computer code. A non-linear analysis was conducted using "Mooney" and "Herrman" constitutive theory. The models were subjected to incremental inflation pressures. Stresses and displacements were compared to experimental data available. The cast carcass tire displacements correlated very well with actual displacements as a function of inflation pressure. The bias-ply tire results were not as satisfactory. This study was conducted under ASIAC Problem No. 108.

The work was done by the Aerospace Structures Information and Analysis Center, which is operated for the Air Force Flight Dynamics Laboratory by Anamet Laboratories, under Contract No. F33615-77-C-3046.

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SECTION 1
INTRODUCTION

This analysis was conducted for AFFDL/FEM to demonstrate the ability of the MARC computer code to perform non-linear problems having either large displacements and/or large strains and to compare those results to experimental data and a FEM funded computer code developed by Dr. Deak (Ref. [1] and [2]*). Two sample cases were used to test the MARC capability. The first was an isotropic cast carcass tire. The second was a bias-ply tire which required the use of orthotropic elements. Experimental data in the form of crown and sidewall displacements as a function of inflation pressure existed for both of these cases.

The MARC finite element computer code was selected for use in this study because it was capable of handling non-linear problems containing large displacements and/or large strains. It contains special elements offering both a "MOONEY" and a "HERRMAN" constitutive theory. MARC has been undergoing continuous development, proceeding from version "F" to version "H3" between August 1977 and August 1978. The "H" version supposedly contained an orthotropic capability for MOONEY and HERRMAN materials. However, it never functioned as indicated in the User's Manual (Ref. [3]) until version "H3", when the orthotropic matrix for materials could be input directly into the program. It was then possible to obtain meaningful results for the bias-ply tire. The isotropic case of the cast carcass tire had presented no such problems. Considerable time was required to become familiar with the operation of MARC because of the complexity of the various capabilities. The list of available elements also grew from 33 to 61 during this period offering additional options for analysis.

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*Numbers in brackets indicate references at end of report.

The isotropic cast carcass tire was analyzed and compared to experimental data. The model was inflated incrementally to 150 psi. The cross-section displacements matched the experimental data very well. A centrifugal force was then added, which simulated a spin-up of the tire to a forward velocity of 150 mph. The stresses at the rim of the tire were above the yield point for the material although they were below the tensile failure limit. The actual tire had survived these loads, indicating that the analysis predictions were incorrect.

The 6-ply tire was modeled and analyzed following the method used by Dr. Brewer in Ref. [4] and Dr. Deak in Ref. [2]. The MARC results were better than the DEAK results, but still did not match the experimental data. MARC underestimates the displacements during the initial inflation of the tire and overestimates them as the pressure increases.

Additional analysis involving a contact problem with the cast carcass tire and with an anisotropic tread belt vulcanized to the cast carcass tire had been planned. It was decided not to continue the analysis since MARC was obviously failing to predict the tire behavior. It has not been determined whether this is due to the program itself or in the modeling techniques used.

SECTION 2
THE CAST CARCASS TIRE

The cast tire was modeled with an axisymmetric element (Element 28 in the MARC element list). It was necessary to model only one half of the cross-section of the tire by taking advantage of symmetry. The idealized model is shown in Figure 1. The model was rigidly constrained at the flange or rim of the tire.

In performing a non-linear analysis with MARC, it is necessary to increment the load in small increments. For the original run, the load was increased in ten psi. increments up to 150 psi. The landing velocity of 150 mph was then simulated by spinning the model up to 264.66 rad/sec. in ten equal increments. This run required 341 CP seconds and 1302 IO seconds with 160,000 octal words of memory. Closer analysis of this run showed residual forces as high as 250 pounds occuring at the first increment of 10 psi. These reduced consistently to only a few pounds at higher loads. Since the residuals are an indication of error due to step size, the model was rerun in smaller steps.

For this run the load was increased in one psi. increments from zero to 20 psi., and two psi. increments from 22 to 150 psi. It was then spun up in 20 equal increments. This run required 1227 CP seconds and 4428 IO seconds of computer time with a 160,000 octal word core memory. This time the largest residual at one psi. was 2.5 pounds. This represented an improvement by a factor of 100 in the residual by reducing the step size by a factor of ten. However, analysis of the stresses and displacements showed less than one per cent change in the results. This indicates that for this purpose the increase in accuracy is scarcely warranted since the computer cost increased by a factor of three.

Figures 2 through 7 are plots to scale of the displacement of the tire cross-sections as the pressure increases and after

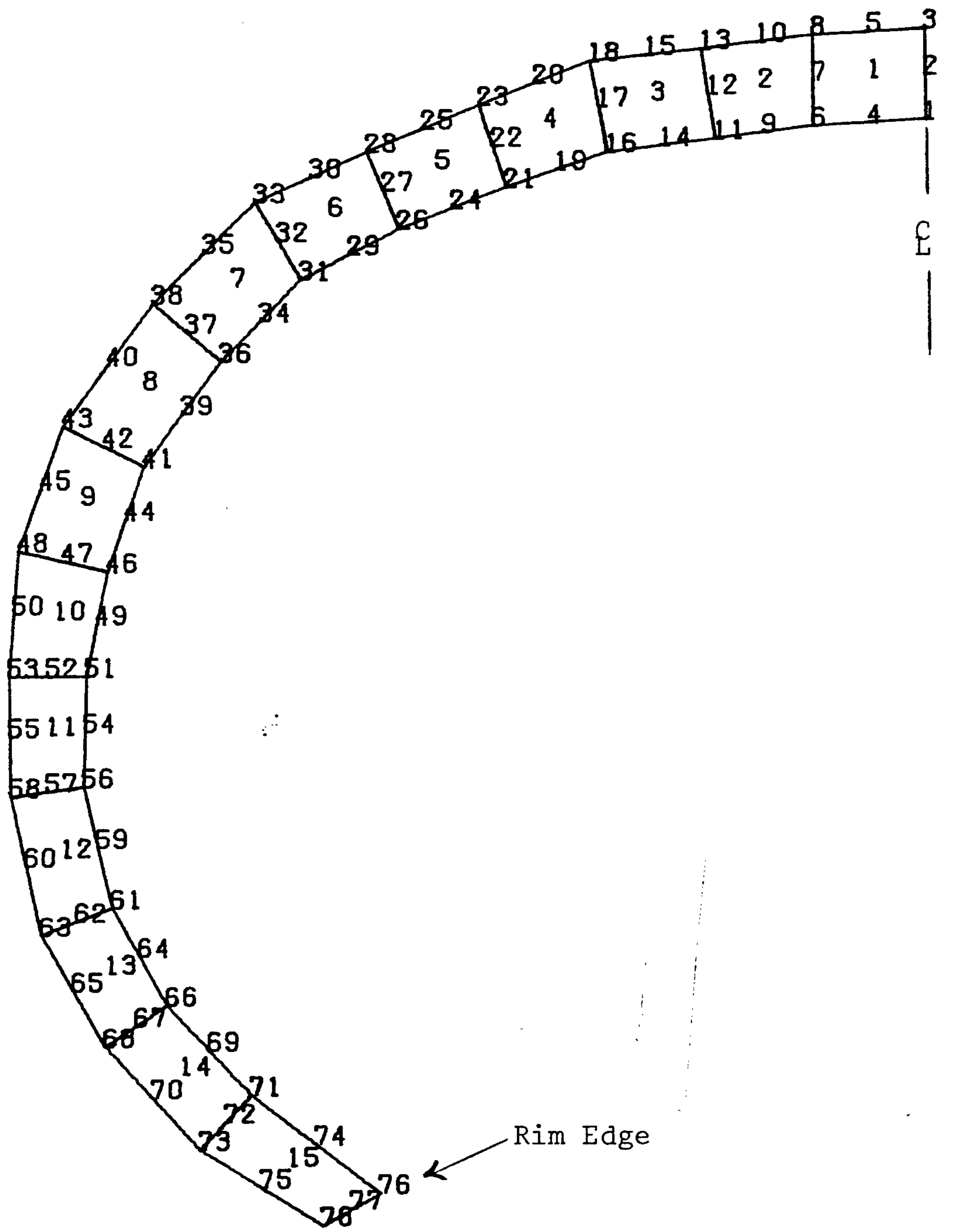

Figure 1. MARC Finite Element Model One Piece Cast Tire

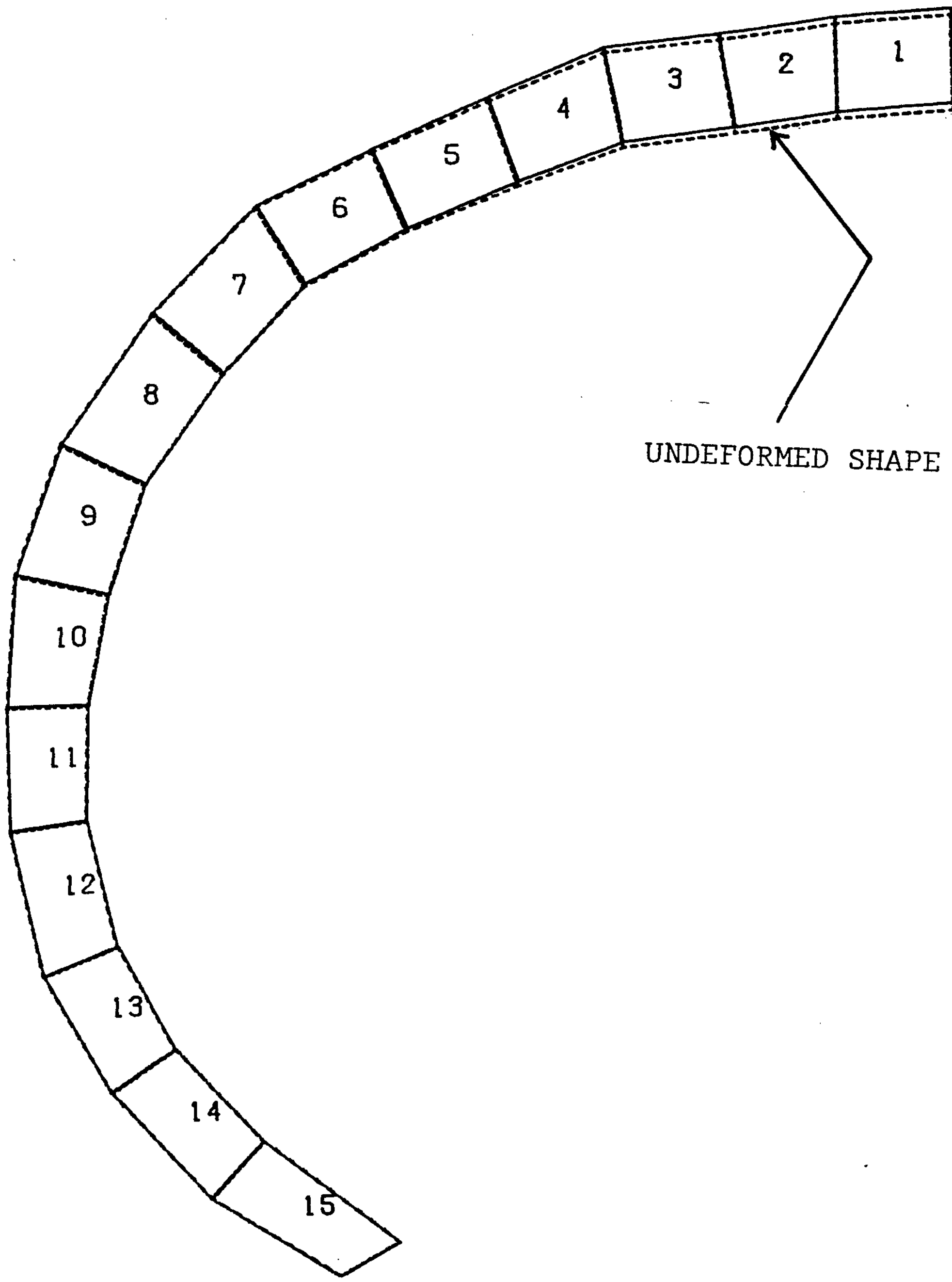

Figure 2. Displacement Plot at 10 psi. One Piece Cast Tire

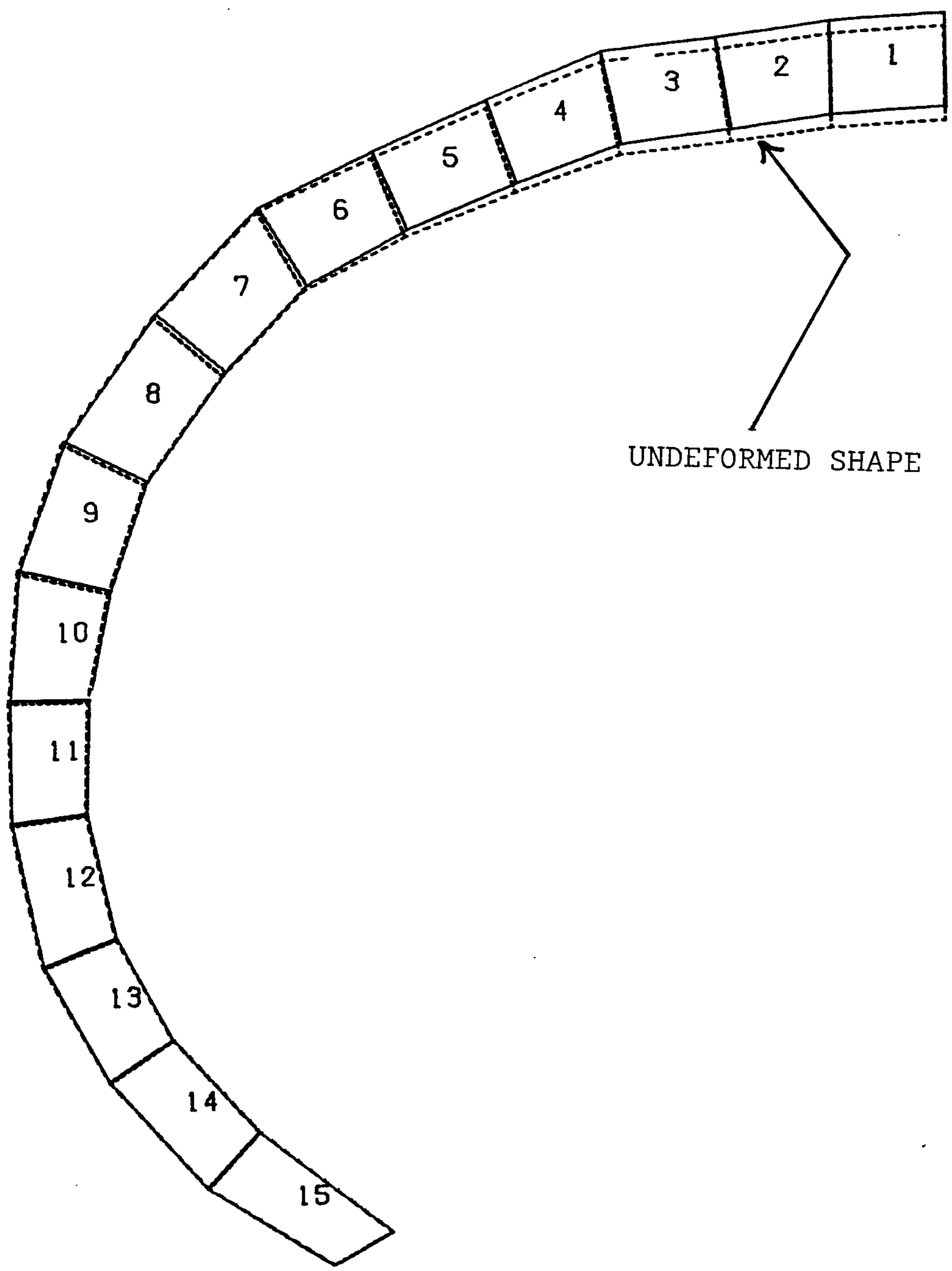

Figure 3. Displacement Plot at 20 psi. One Piece Cast Tire

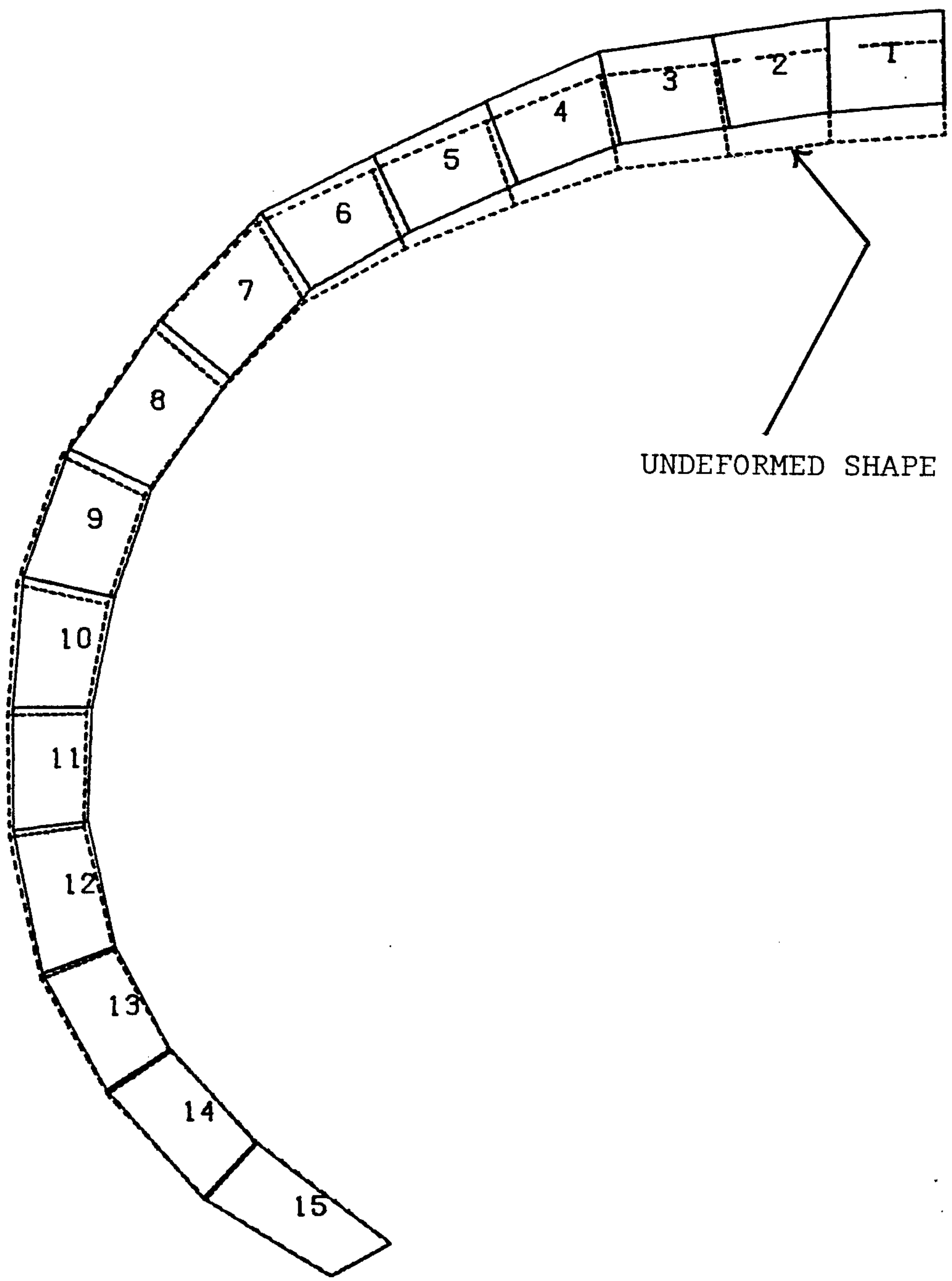

Figure 4. Displacement Plot at 50 psi. One Piced Cast Tire

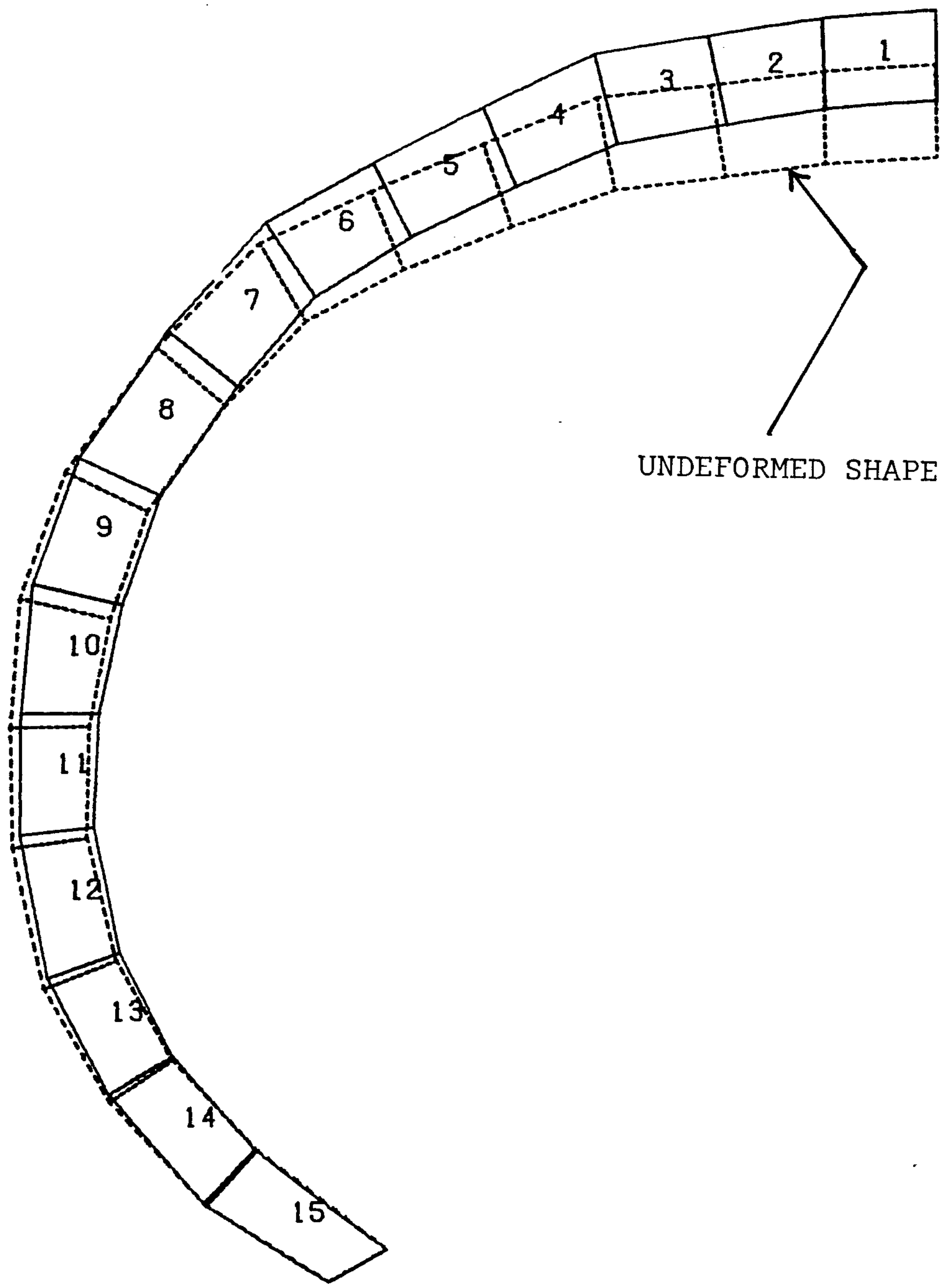

Figure 5. Displacement Plot at 100 psi. One Piece Cast Tire

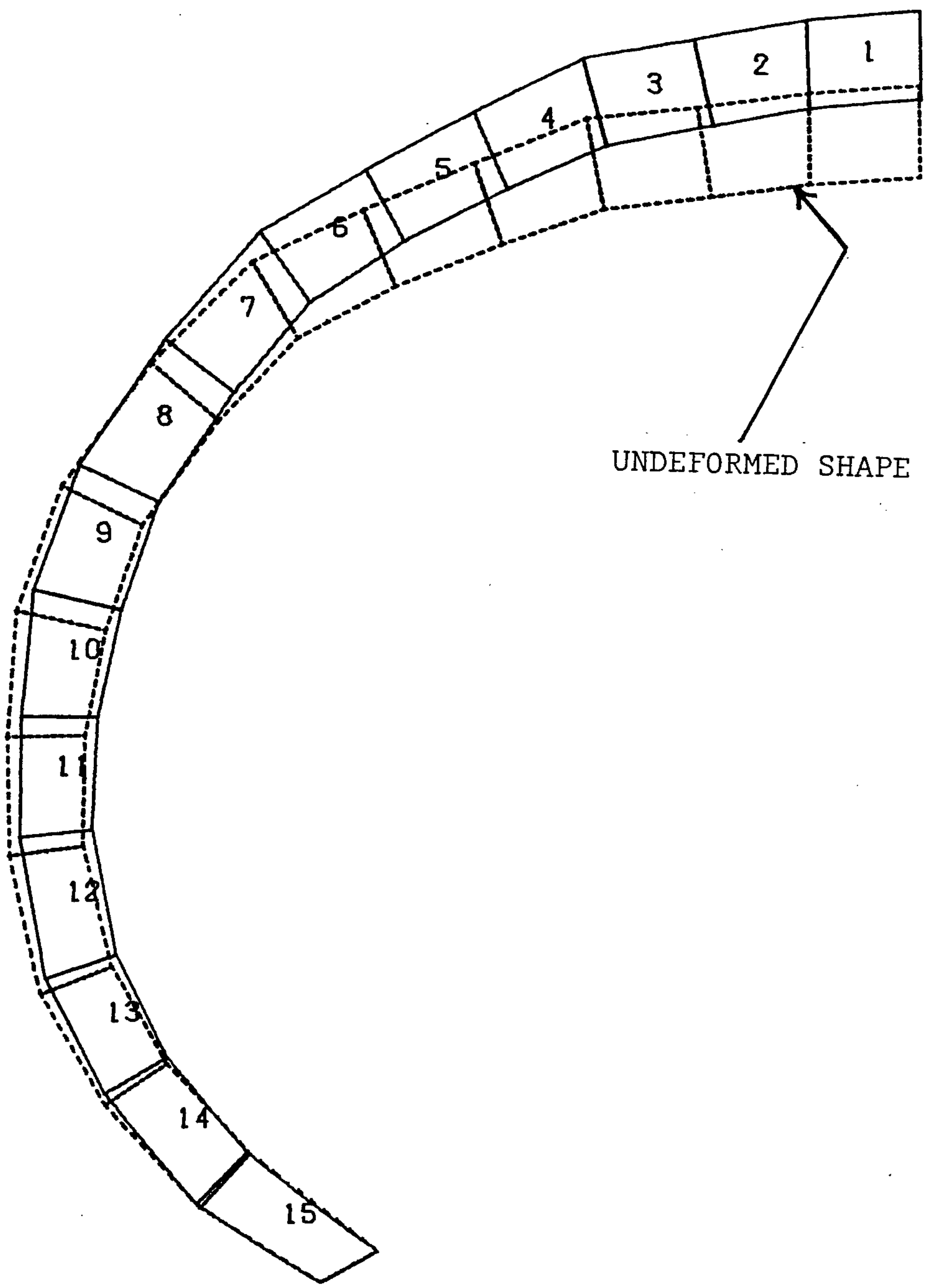

Figure 6. Displacement Plot at 150 psi. One Piece Cast Tire

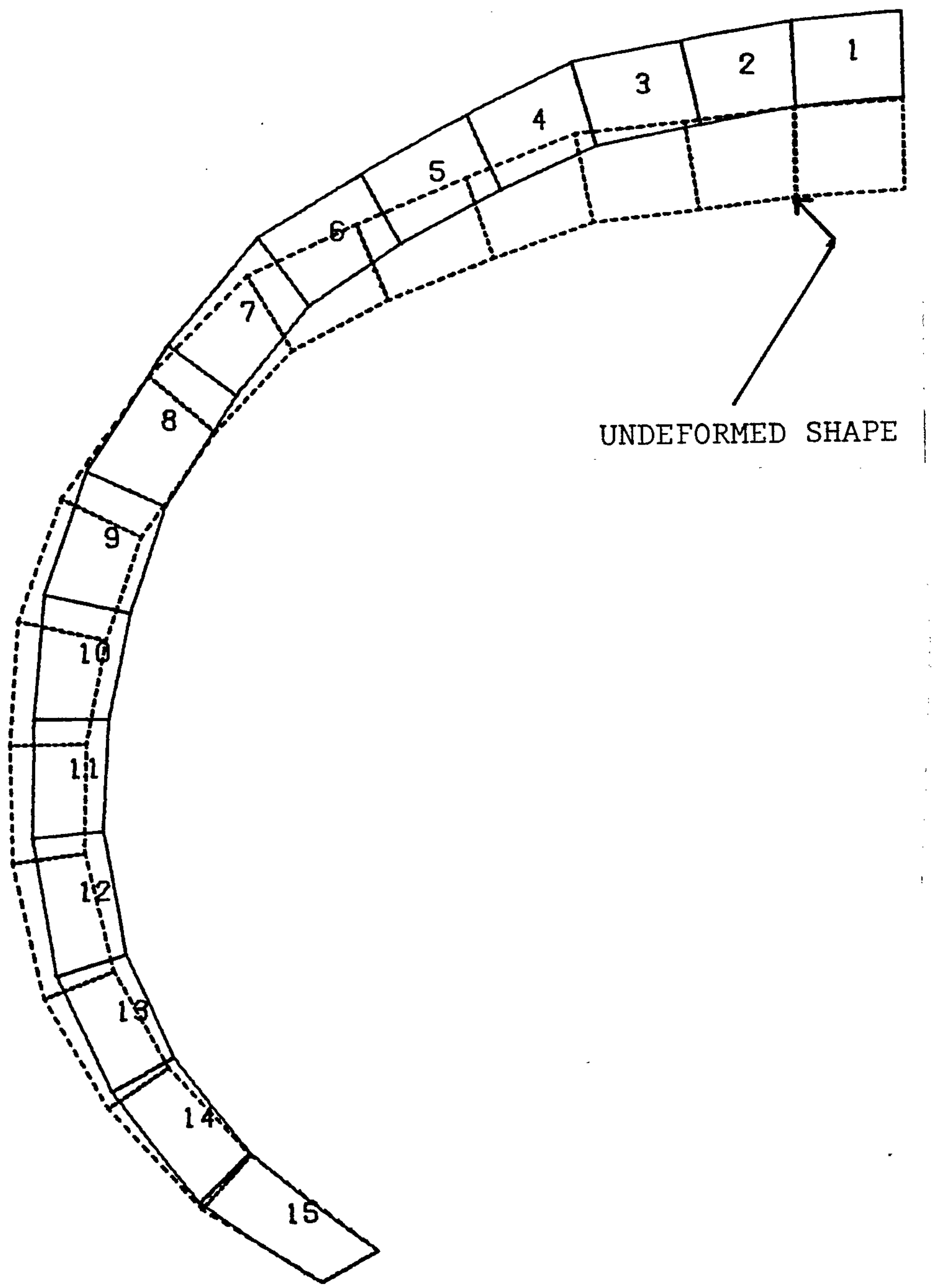

Figure 7. Displacement Plot at 150 psi. with Spin-Up One Piece Cast Tire

spin-up is added to the pressurized tire. These displacements are also tabulated in Table 1. These computed values are compared to experimental data in Figures 8, 9, and 10. The computed displacement of the crown of the tire follows the experimental data exactly out to 50 psi. It then begins to taper off slowly while the experimental data remained linear out to 150 psi. The computed sidewall displacement matches the experimental data quite well as can be seen in Figure 9. Surprisingly, during spin-up the side wall continued to move outward (or laterally) more than radially as can be seen from Figures 9 and 10 and also from Figures 6 and 7. This would not normally be expected as a function of the centrifugal force and it must be due to the interaction of the pressurized tire and the rotation.

Figures 11 through 16 illustrate the most significant stresses found in the tire as a function of load. They are also tabulated in Table 2. The peak shear stress of 939 psi. occurs in element 14, slightly removed from the rim of the tire. The peak tensile stress occurs at the rim with a value of 3117 psi. This is above the yield strength of 2730 given in Table A-10 of Ref. [5]. This yield point is reached when the pressurized tire reaches a velocity of approximately 75 mph. The actual tire had withstood this inflation and taxi conditions which created both spin-up and taxi loads without failure. It therefore appears that the MARC model was overestimating the actual stresses in the tire.

Table 1. One Piece Cast Tire - Displacements (inches)

	CROWN DEFLECTIONS NODE 3 (RADIAL)		SIDE WALL DEFLECTIONS (NODE 53) RADIAL		SIDE WALL DEFLECTIONS (NODE 53) TRANSVERSE	
LOAD(PSI)	INCREMENT	TOTAL	INCREMENT	TOTAL	INCREMENT	TOTAL
10	.02873	.02873	.00600	.00600	.00588	.00588
20	.02579	.05452	.00603	.01203	.00541	.01129
30	.02550	.08002	.00601	.01804	.00532	.01661
40	.02429	.10431	.00600	.02404	.00509	.02170
50	.02350	.12781	.00596	.03000	.00488	.02658
60	.02262	.15043	.00593	.03593	.00468	.03126
70	.02186	.17229	.00590	.04183	.00447	.03573
80	.02114	.19343	.00586	.04768	.00427	.04000
90	.02048	.21391	.00581	.05349	.00407	.04407
100	.01986	.23377	.00577	.05926	.00388	.04795
110	.01929	.25306	.00572	.06499	.00369	.05164
120	.01875	.27181	.00567	.07066	.00352	.05516
130	.01825	.29006	.00562	.07628	.00334	.05850
140	.01779	.30785	.00557	.08185	.00318	.06168
150	.01735	.32520	.00553	.08738	.00301	.06469
W/Spin	.06946	.39466	.02804	.11542	.04774	.11243

Table 2. One Piece Cast Tire - Stresses (psi.)

TYPE OF STRESS	LOCATION (ELEMENT NO.)	STRESS UNDER LOAD 150psi	150psi W/Spin
SHEAR	1	87	91
HOOP	1	1873	2185
AXIAL	1	1266	1320
RADIAL	1	.37	.40
MAXIMUM	1	1873	2185
SHEAR	10	77	66
HOOP	10	1027	883
AXIAL	10	21	9
RADIAL	10	833	874
MAXIMUM	10	1027	883
SHEAR	14	803	938
HOOP	14	664	729
AXIAL	14	657	612
RADIAL	14	511	462
MAXIMUM	14	1390	1479
SHEAR	15	584	641
HOOP	15	1460	2182
AXIAL	15	1987	2689
RADIAL	15	1265	2155
MAXIMUM	15	2312	3117

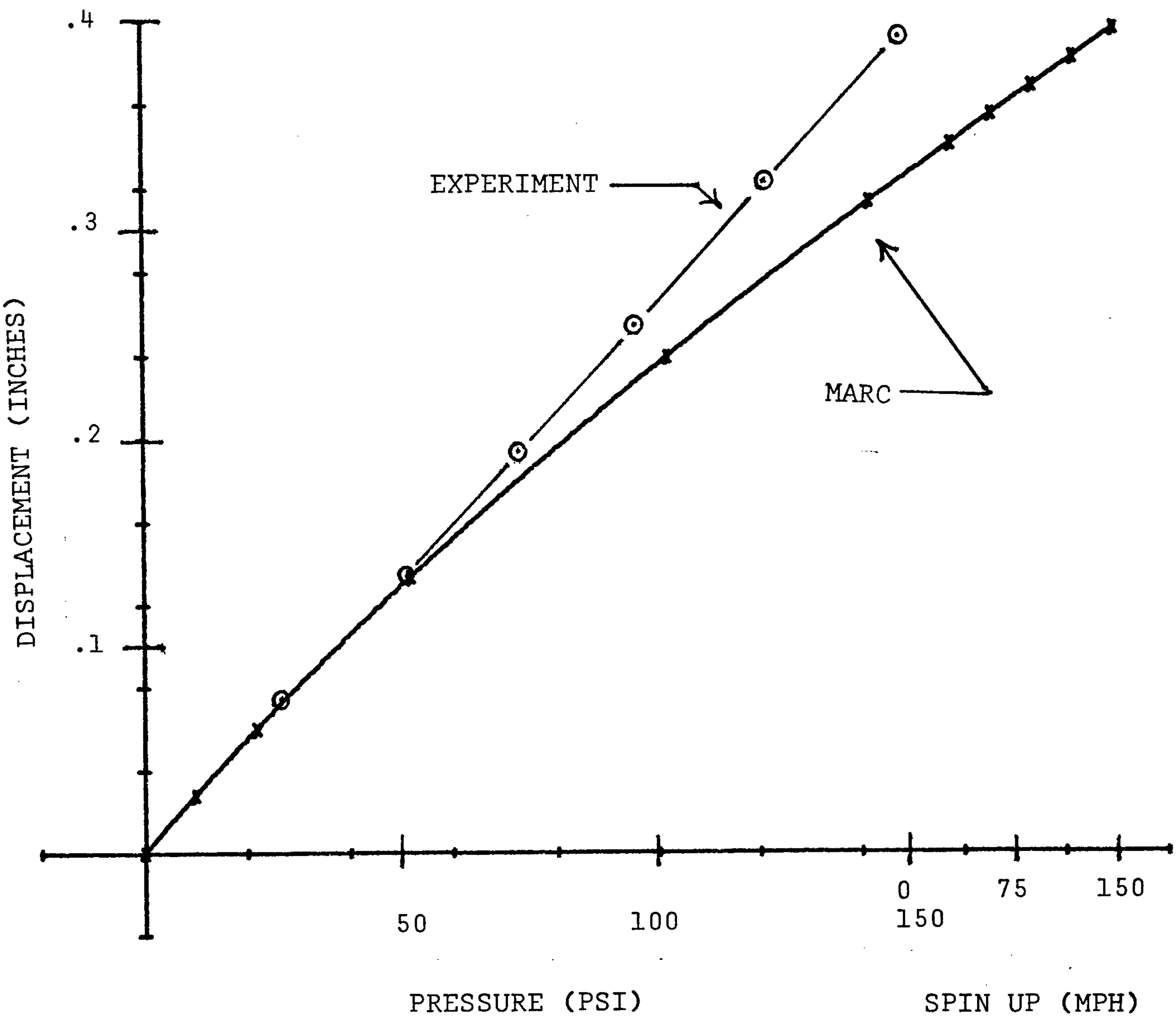

Figure 8. Crown Displacement (Radial-Node 3), One Piece Cast Tire

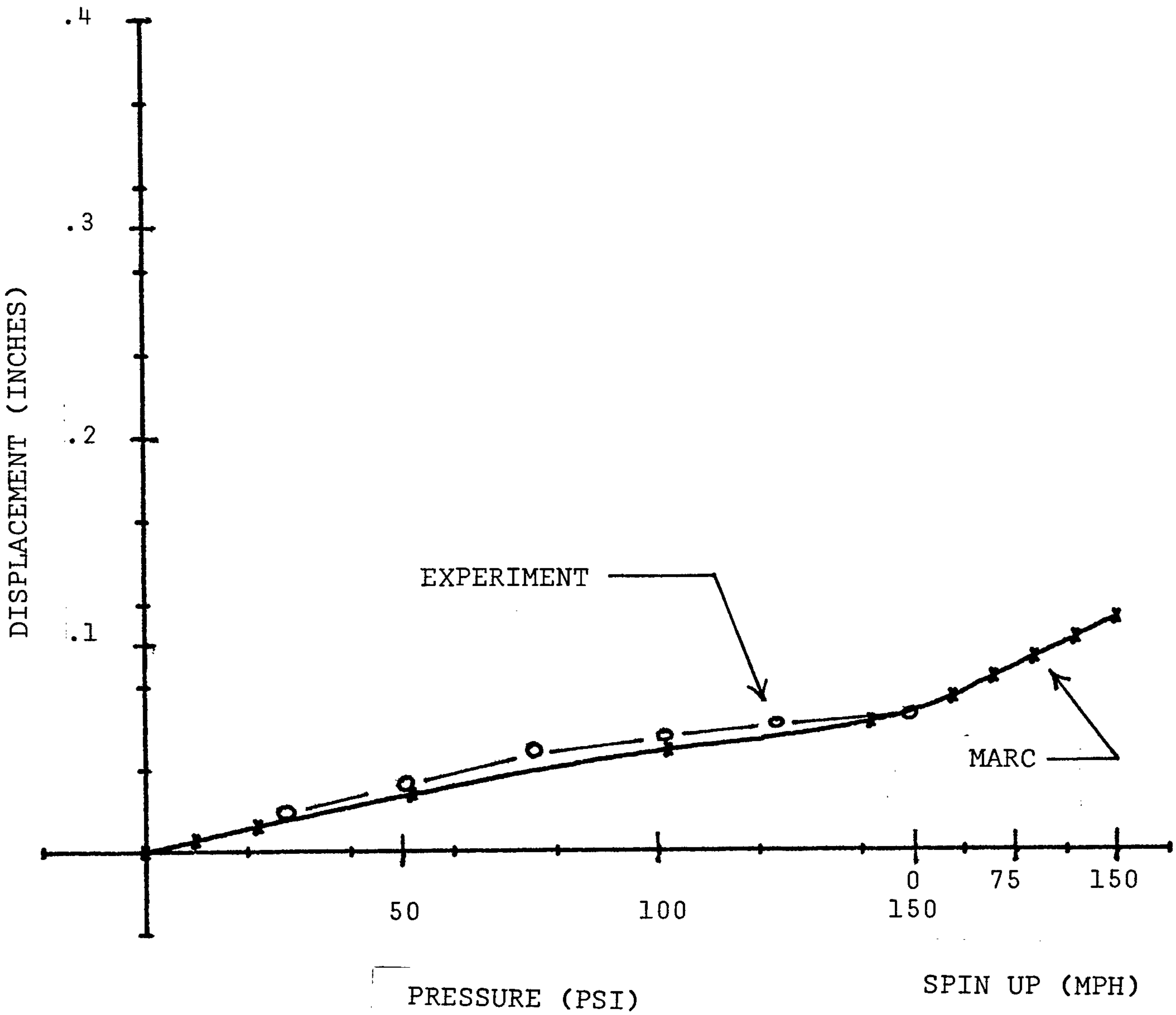

Figure 9. Sidewall Displacement (Lateral-Node 53), One Piece Cast Tire

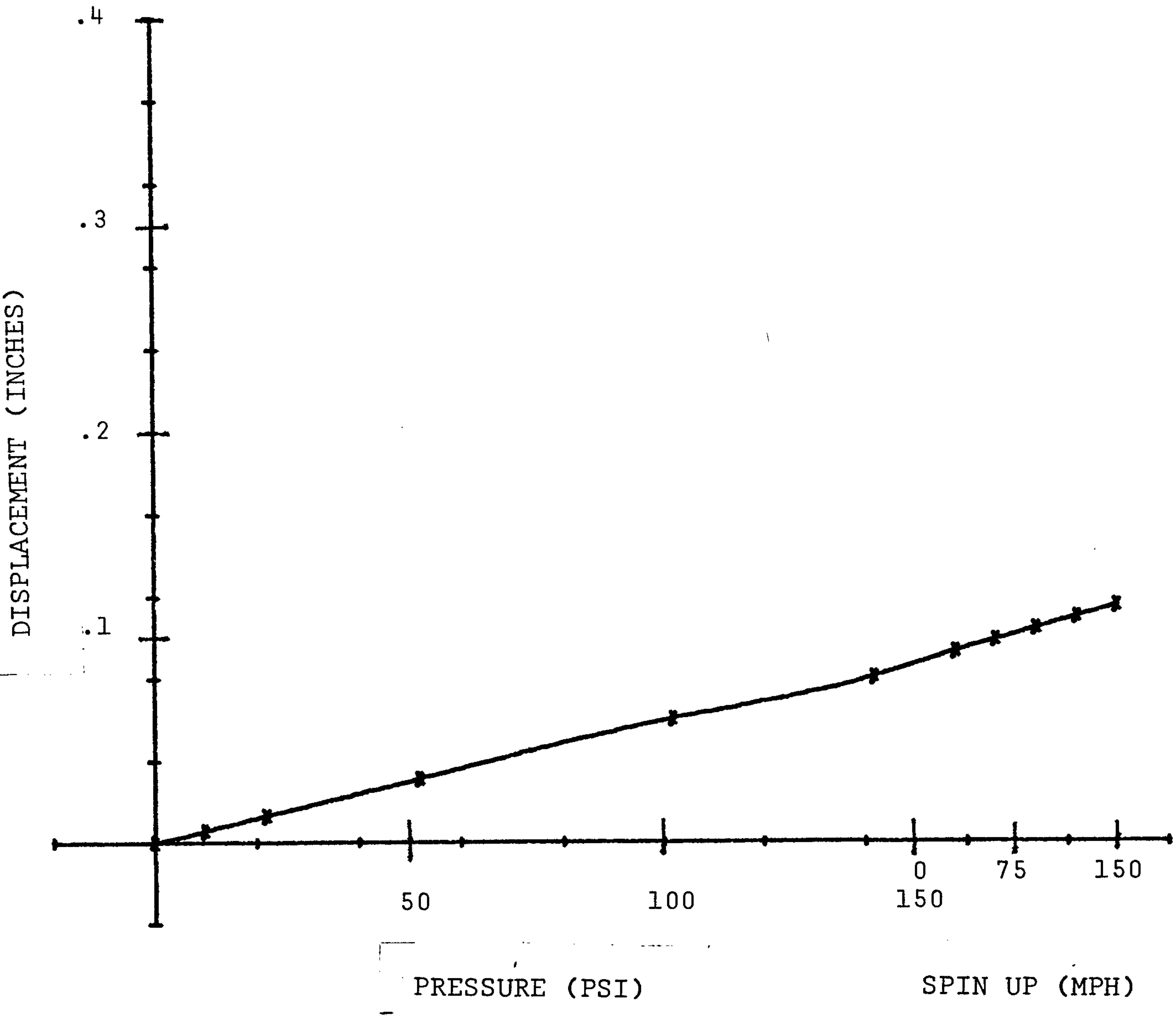

Figure 10. Sidewall Displacement (Radial-Node 53), One Piece Cast Tire

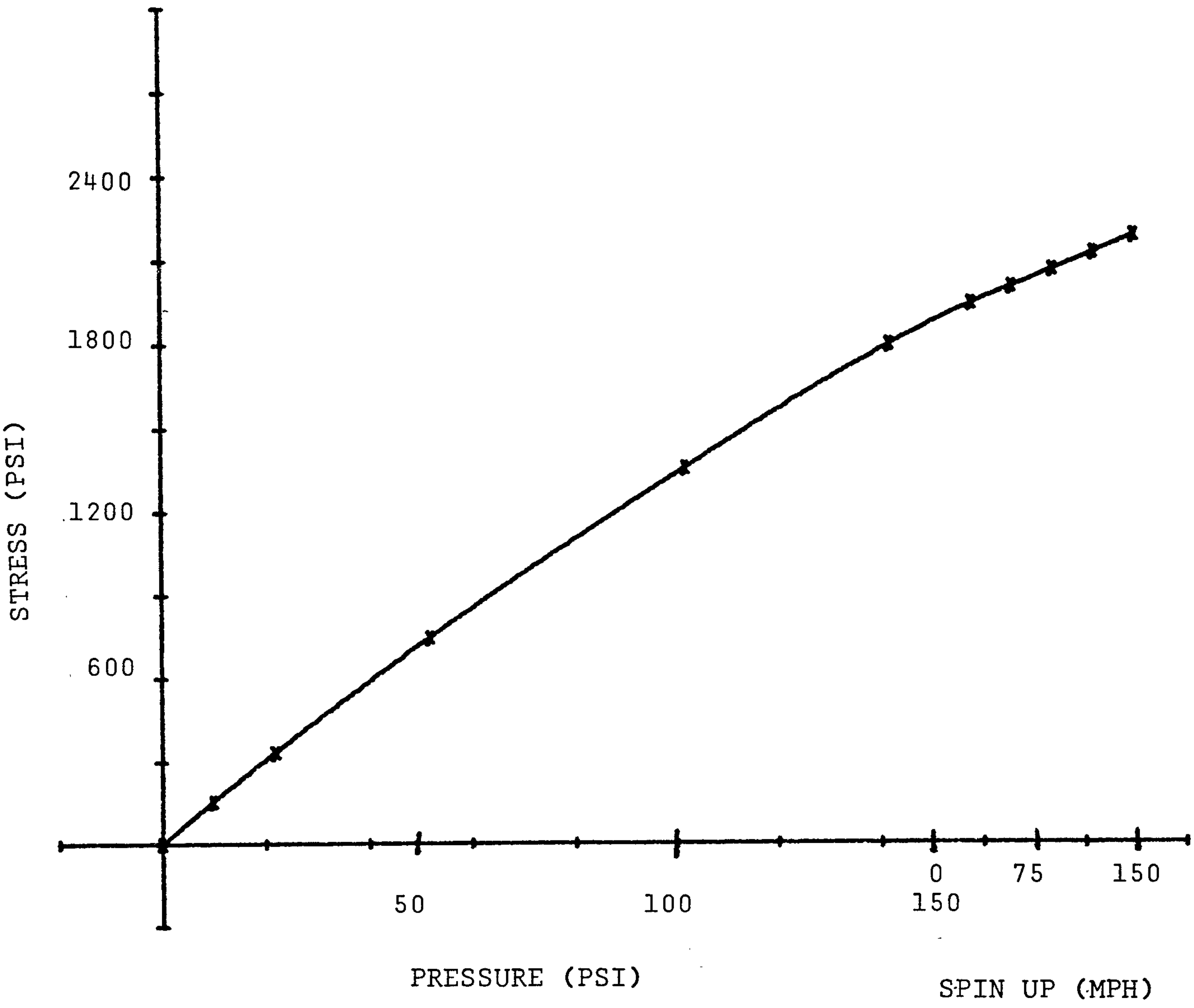

Figure 11. Hoop Stress at Crown (Element 1), One Piece Cast Tire

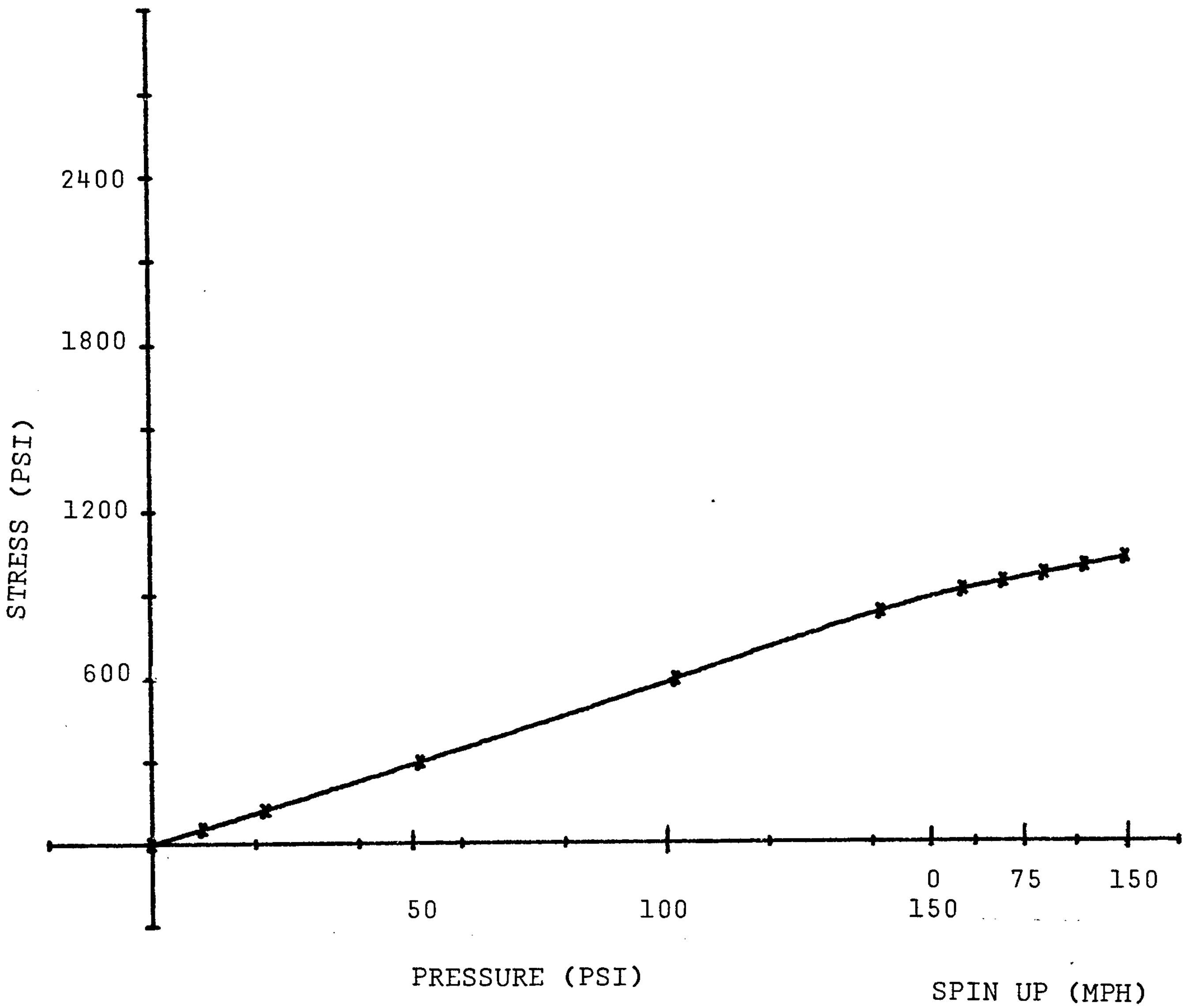

Figure 12. Hoop Stress in Sidewall (Element 10), One Piece Cast Tire

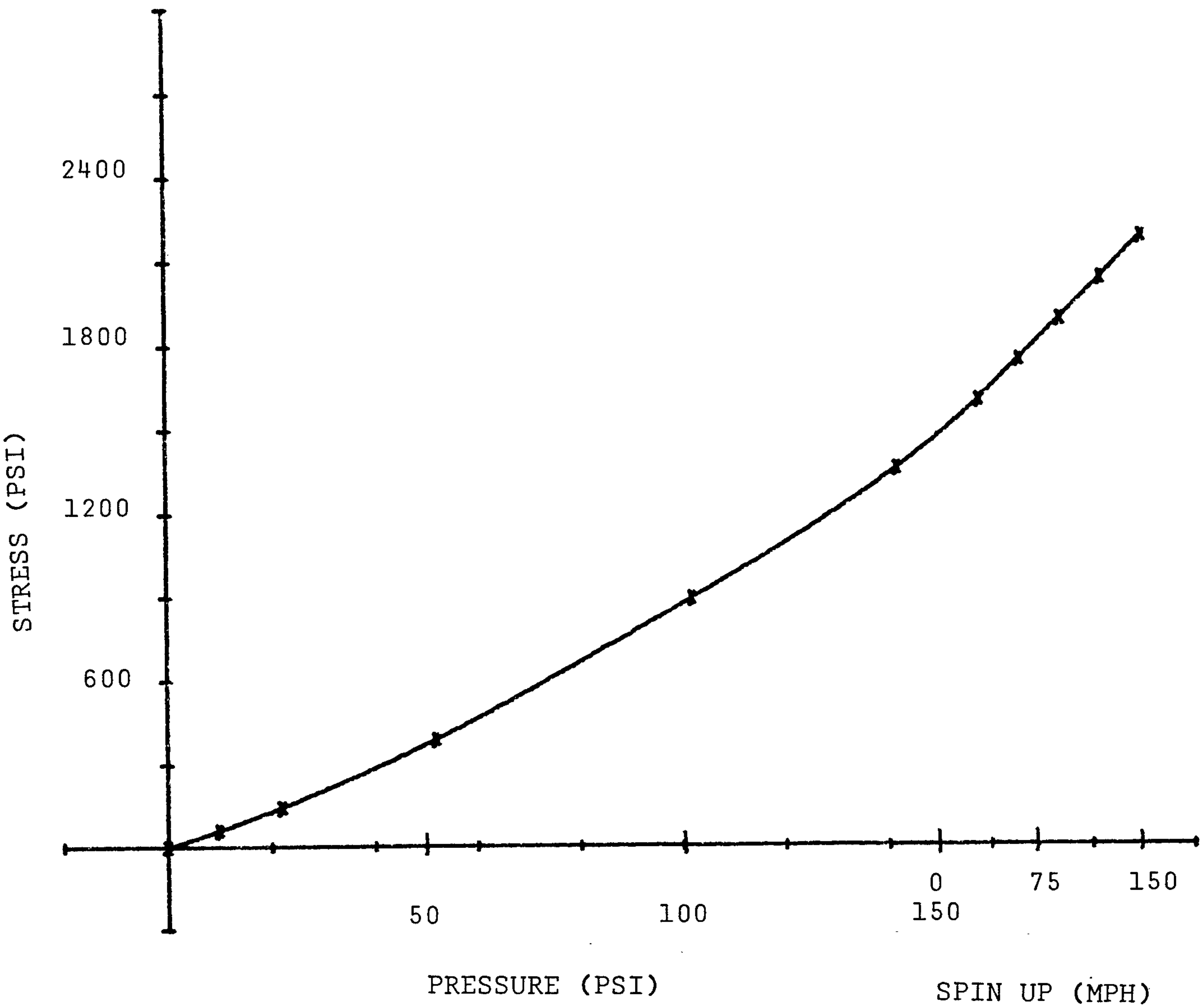

Figure 13. Hoop Stress at Rim (Element 15), One Piece Cast Tire

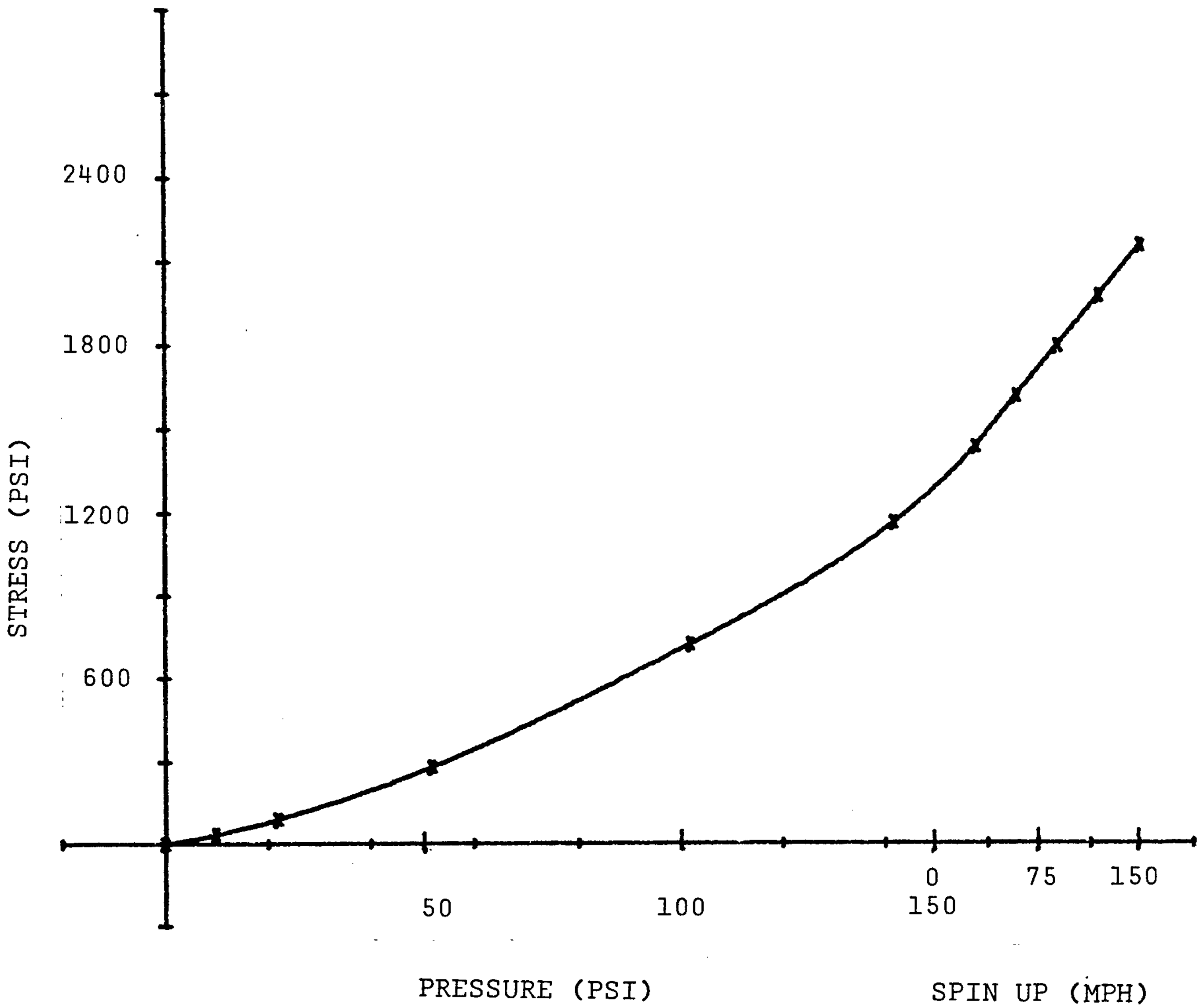

Figure 14. Radial Stress at Rim (Element 15), One Piece Cast Tire

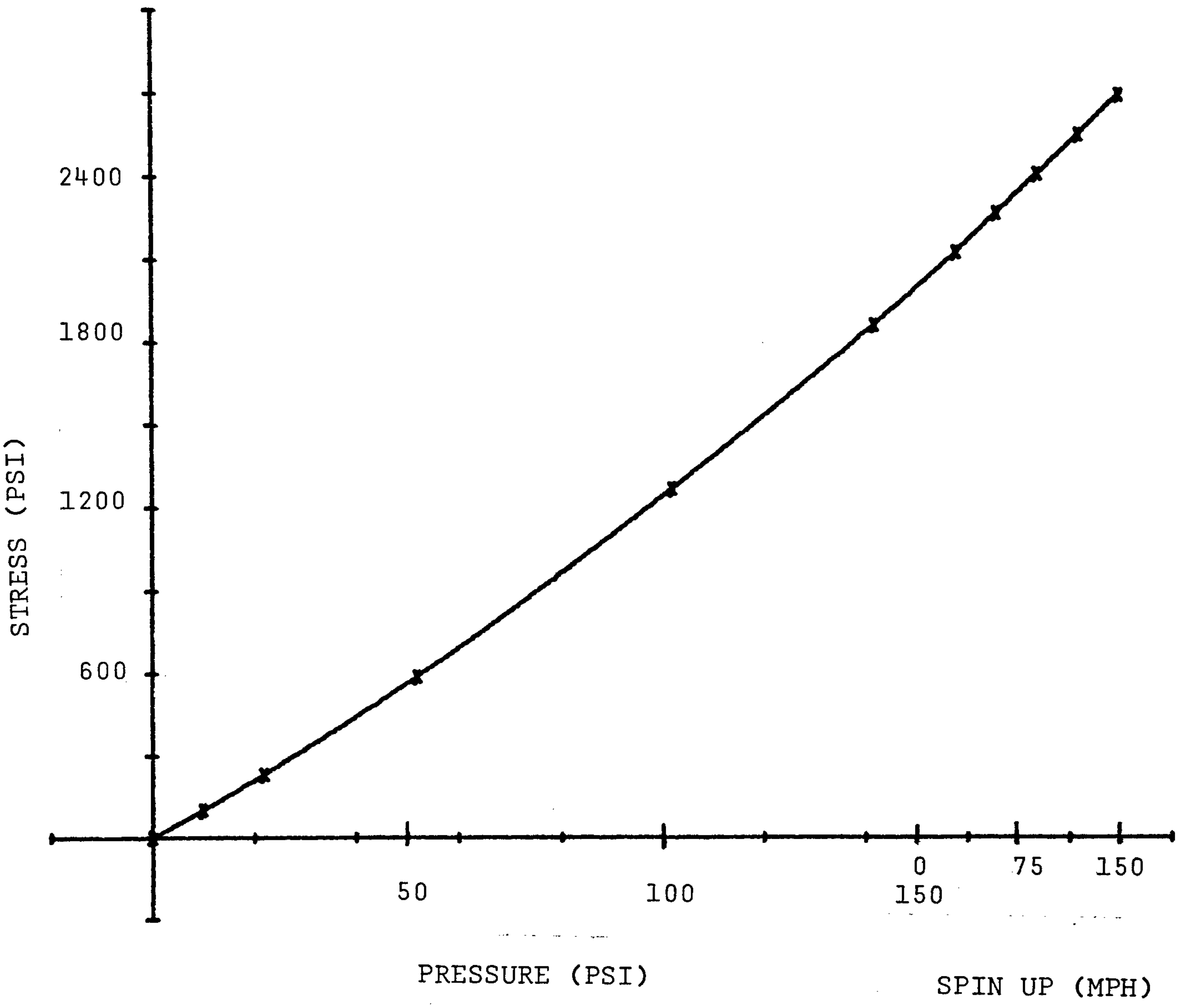

Figure 15. Lateral Stress at Rim (Element 15), One Piece Cast Tire

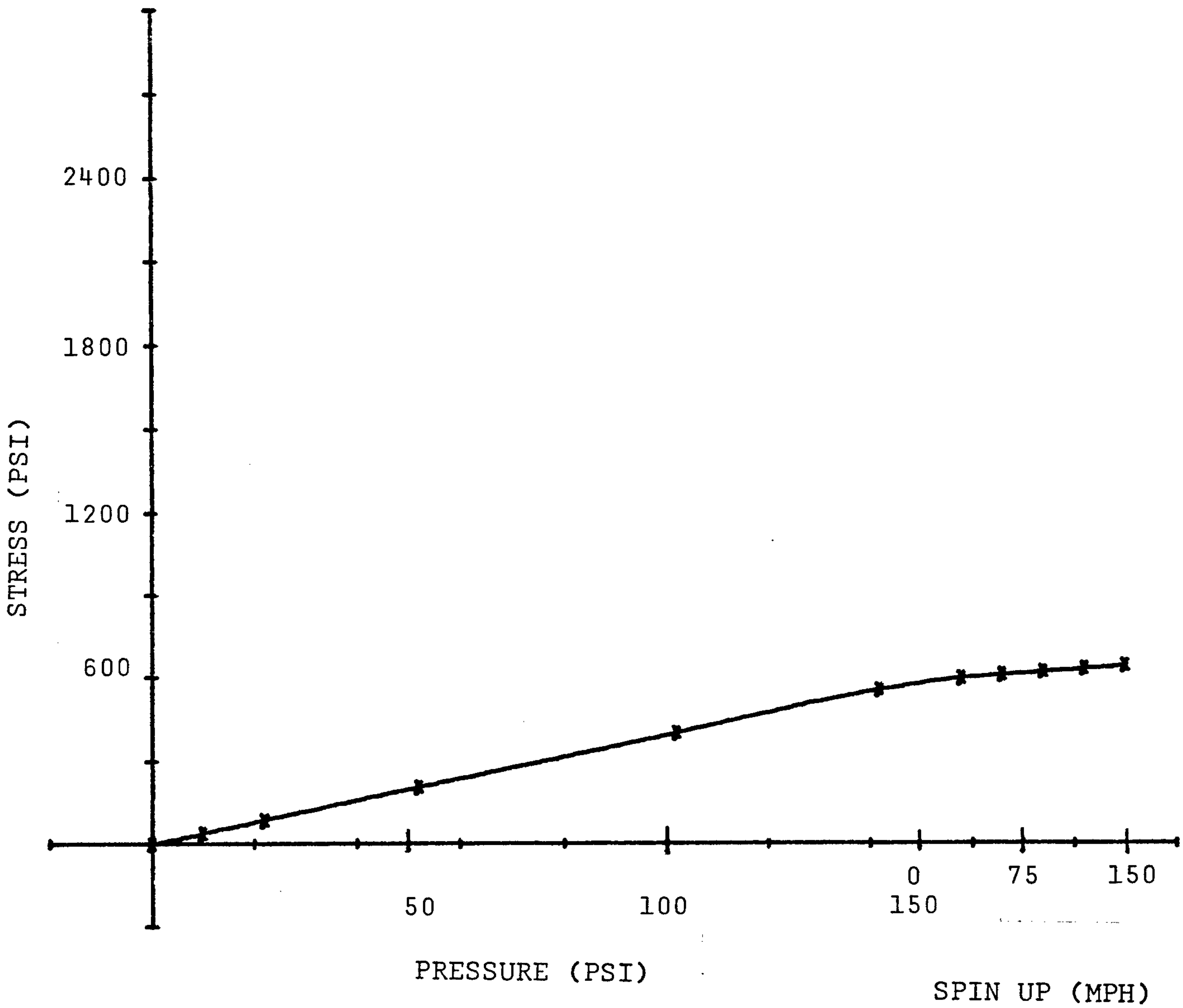

Figure 16. Shear Stress at Rim (Element 15), One Piece Cast Tire

SECTION 3
THE BIAS-PLY TIRE

The anisotropic capability of MARC was tested by copying the bias-ply tire model used by Dr. Brewer (Ref. [4]). The MARC model is shown in Figure 17. The model is similar to the cast carcass model, except that MARC element 33 using the HERRMAN formulation of the constitutive theory was used.

The tire model was inflated in small increments because the residuals tended to be large. The load was increased in 0.5 psi. increments from zero to 1.0 psi., 1.0 psi. increments from 1.0 psi. to 10.0 psi., and 2.0 psi. increments above 10.0 psi. At 68.0 psi., the analysis terminated because of a failure to converge to energy criterion. Other incrementation step levels were tried, but convergence always failed, apparently due to the highly orthotropic properties. The case cited is the step size that ran the longest before convergence failed.

Plots of the tire deformation are shown in Figures 18 and 19. Comparison of these to experimental data in Ref. [4] shows that the sidewall of the MARC model is apparently far too weak. A comparison of the crown displacement to those obtained by Brewer (which very closely approximates experimental data) and those obtained by Deak using his program is given in Figure 20. The MARC solution crosses the Brewer solution at about 65 psi., underestimating the crown displacements below that and overestimating them above that pressure. From this plot, the MARC solution appears to give better results than either DEAK solution, however, the MARC model still does not match the nonlinear behavior of the bias-ply tire. The MARC data contains only a very slight decrease in slope with increasing pressure in comparison to experimental data.

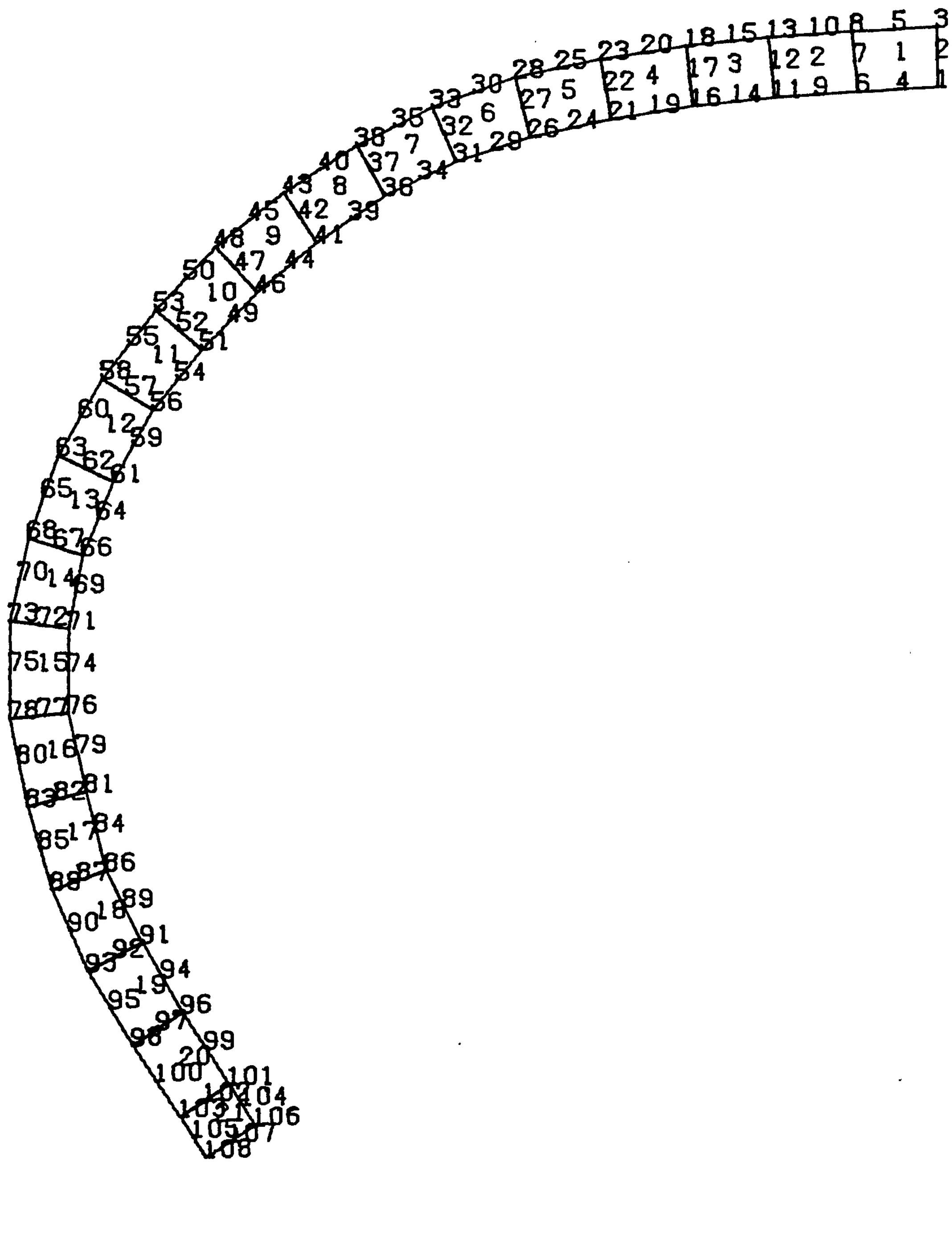

Figure 17. MARC Finite Element Model, Bias-Ply Tire

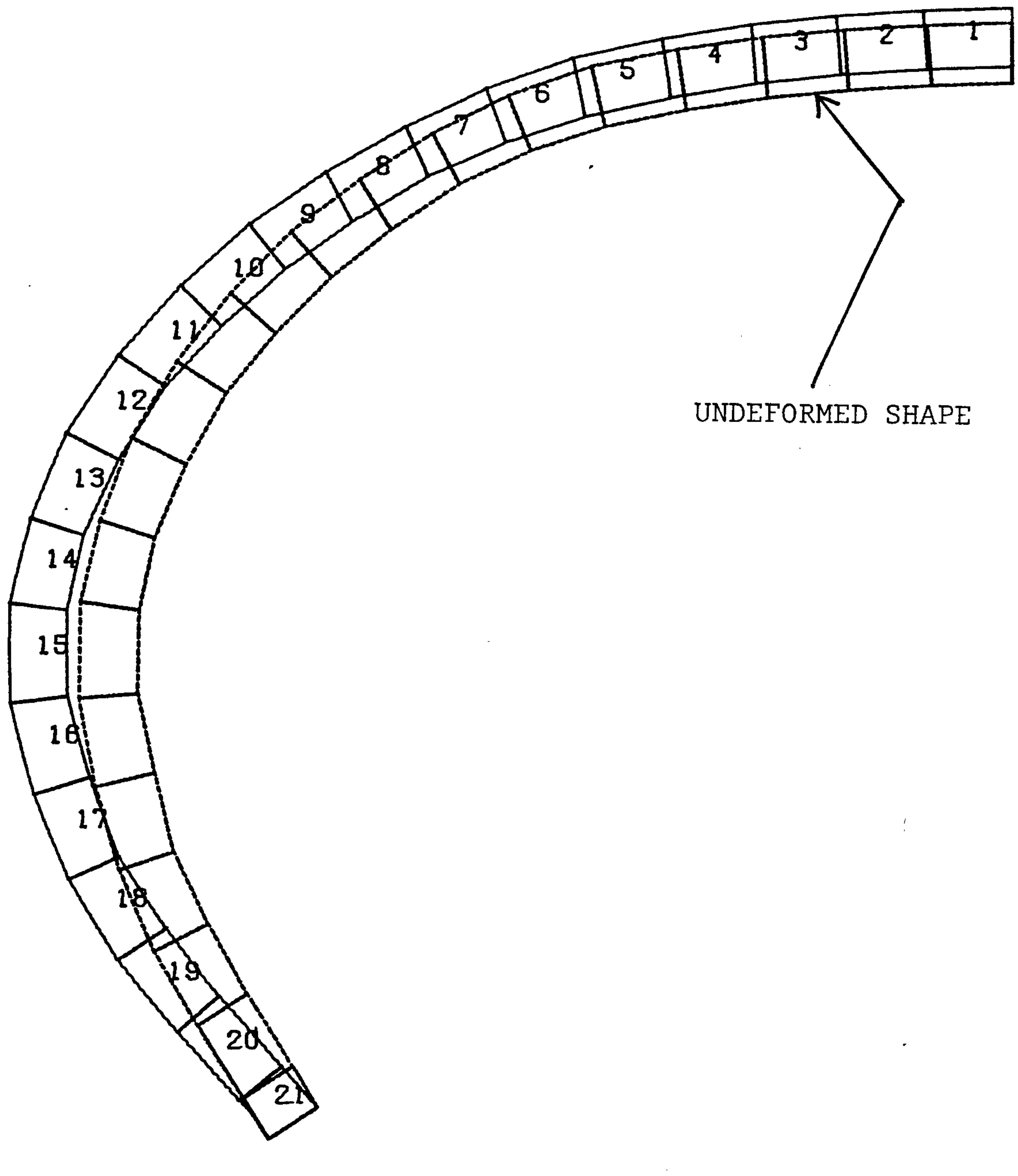

Figure 18. Displacement Plot at 10 psi., Bias-Ply Tire

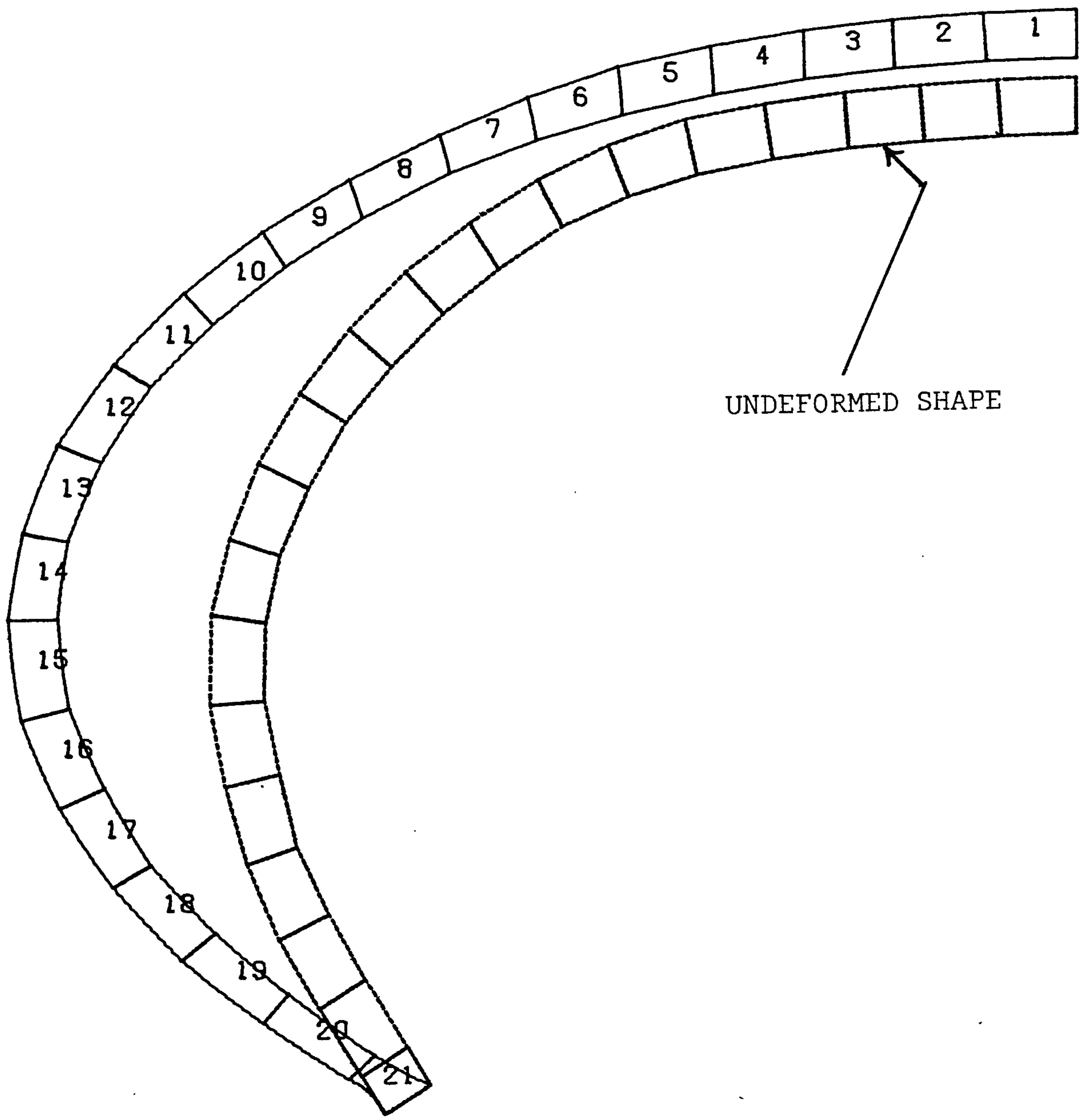

Figure 19. Displacement Plot at 50 psi., Bias-Ply Tire

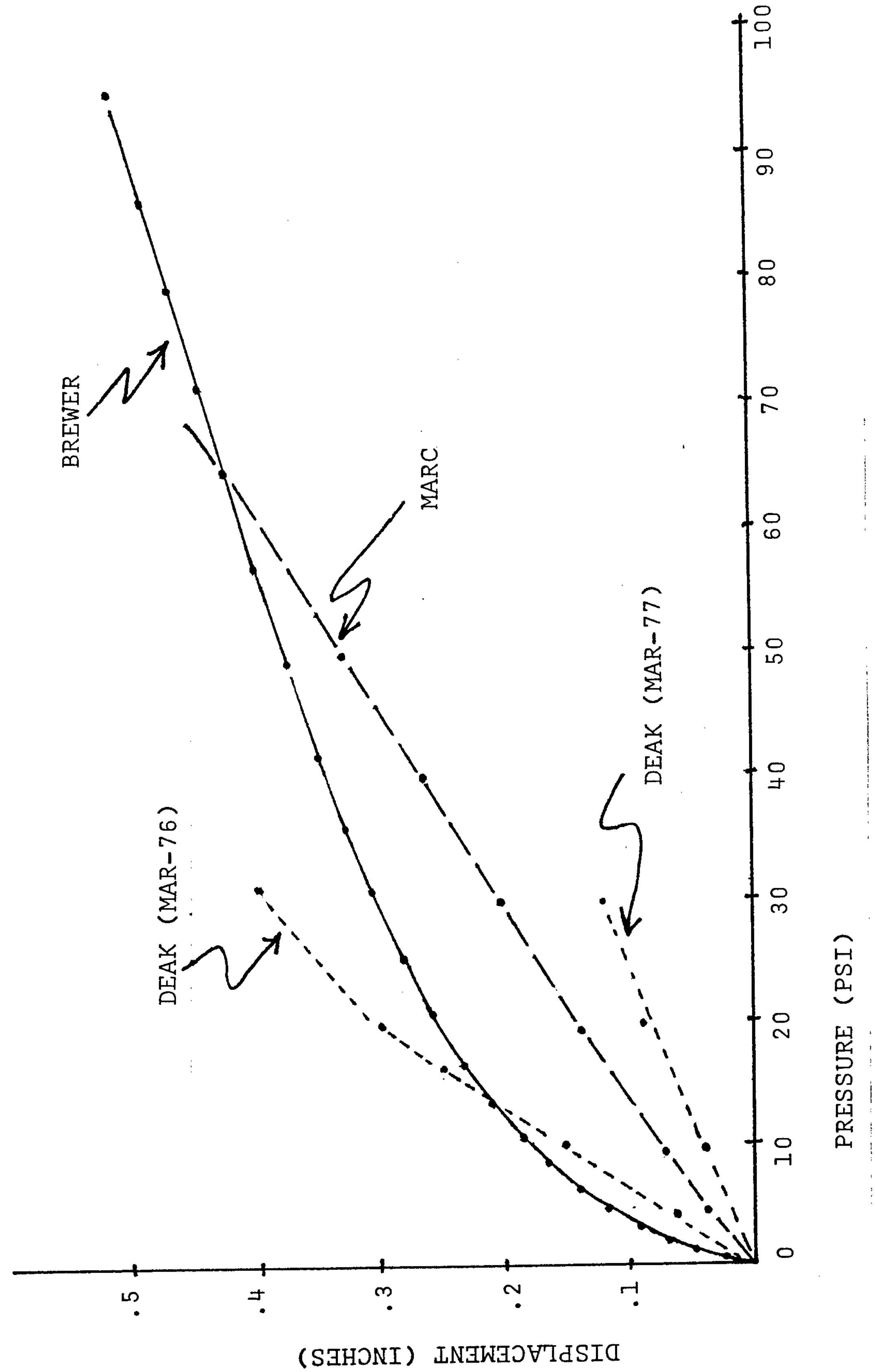

Figure 20. Crown Displacement (Radial-Node 3), Bias-Ply Tire

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